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TITLE OF THE INVENTION

SEMICONDUCTOR DEVICE AND METHOD FOR PRODUCING A  
SEMICONDUCTOR DEVICE

5                   BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to a semiconductor  
device having a capacitor constituting a dynamic random  
access memory (DRAM) cell wherein the capacity of the  
10 capacitor is increased by roughening a surface of the  
cylindrical toragse node, and a method for producing such  
semiconductor device.

DISCUSSION OF BACKGROUND

Figure 6 is a cross-sectional view of a conventional  
15 semiconductor device as disclosed in JP-A-9-186297.  
Figure 6 shows mainly the structure of a cylindrical  
capacitor in cross section, which constitutes a DRAM cell.  
In Figure 6, reference numeral 101 designates a  
semiconductor substrate, numeral 101a designates a  
20 source/drain region as a transistor element formed in a  
surface region of the semiconductor substrate 101,  
numeral 102 designates a device isolation oxide layer  
formed on the surface of the semiconductor substrate 101,  
a numeral 103 designates a word line formed on the  
25 semiconductor substrate 101 through a gate insulating  
film, which constitutes a gate electrode of the  
transistor element, numeral 104 designates an interlayer

insulating film formed on the transistor element, numeral 105a designates a cylindrical storage node formed in contact with a source/drain region 101a between adjacent source/drain regions, which is provided with a cylindrical portion extending upward at a position on the interlayer insulating film 104, numeral 106 designates a dielectric film formed on the cylindrical storage node 105a, and numeral 107 designates a cell plate laminated to cover an outer surface of the dielectric film 106.

10 The cylindrical storage node 105a, the dielectric film 106 and the cell plate 107 constitute a cylindrical capacitor 108.

In the conventional semiconductor device shown in Figure 6, the surface area of the storage node is increased by forming a plurality of pin holes 105aa in a cylindrical portion of the cylindrical storage node 105a.

A silicon layer constituting the cylindrical storage node 105a is formed by using a vapor-phase epitaxy method at a temperature which is higher than a temperature for forming an amorphous structure but lower than a temperature for forming a polycrystalline structure while an impurity gas is introduced therein.

However, since thus formed silicon layer has crystallized portions in it, that portions are easily etched earlier than the other portion. Under such circumstances, when an anisotropic etching is conducted to the silicon layer having locality crystallized

portions, only the crystallized portions are selectively removed whereby pin holes 105aa are formed.

Another conventional technique for forming a roughened surface is disclosed in JP-A-7-74268. Figure 7 shows the structure of a semiconductor device in cross section formed by such technique.

In the cross-sectional view showing mainly the structure of a cylindrical storage node 105b, the cylindrical storage node 105b has a cylindrical portion in which an inner wall and an upper surface of a bottom portion are roughened. Numeral 109 designates a bit line formed in contact with the other source/drain region 101a between the adjacent source/drain regions. Other reference numerals designate the same or corresponding part shown in Figure 6. The reason why an outer wall of the cylindrical portion of the cylindrical storage node 105b is not roughened in the semiconductor device shown in Figure 7, is to eliminate a disadvantage that when a heat treatment is conducted with use of a silane gas to obtain a roughened surface, spherical silicon grains having an uniform grain size are formed in the outer wall, and there causes short circuit between adjacent storage nodes. Further, there is another disadvantage that the formation of the silicon grains having an ununiform grain size influences the formation of the dielectric film 106 and the cell plate 107 which are conducted subsequently.

In the conventional semiconductor device shown in

Figure 6, some of the pin holes 105aa penetrate from the outer wall to the inner wall of the cylindrical portion of the cylindrical storage node 105a. In this case, a sufficient physical strength can not be assured for the  
5 cylindrical storage node 105a, and there causes the destruction or the breakage of the cylindrical portion in subsequent processes.

In the conventional semiconductor device shown in Figure 7, it was difficult to control the size of the  
10 silicon grains formed to obtain a roughened surface, and scattering of the silicon grain size was large whereby it use difficult to form a roughened surface in the cylindrical portion of the cylindrical storage node 105b.

It has been considered to control the scattering of  
15 the silicon grain size. With a demand of miniaturizing capacitor elements, the film thickness from the outer wall to the inner wall of the cylindrical portion has further been reduced. Under such circumstances, when both surfaces of the outer wall and the inner wall are to  
20 be roughened, silicon grains are entirely formed in the cylindrical portion whereby air gaps are resulted between adjacent silicon grains. In this case, the physical strength of the cylindrical portion can not be assured and there causes the destruction or the breakage of the  
25 cylindrical portion.

It has been considered to roughen both surfaces of the outer wall and the inner wall by controlling the

grain size of the silicon grains to be small. In this case, however, it is required to reduce the grain size of the silicon grains, and it is difficult to increase remarkably the surface area of the cylindrical portion.

5

SUMMARY OF THE INVENTION

It is an object of the invention to eliminate the above-mentioned disadvantages and to provide a semiconductor device having a cylindrical storage node which provides a sufficient physical strength and which increases the surface area by roughening the surface of the cylindrical portion.

In accordance with a first aspect of the invention, there is provided a semiconductor device which comprises a capacitor of a stacked structure including a cylindrical storage node, a dielectric film and a cell plate, wherein the storage node has a cylindrical portion and a bottom portion; an outer wall of the cylindrical portion which is in contact with the dielectric film has a roughened surface; and an inner wall of the cylindrical portion has a smoothed surface.

In a second aspect of the present invention, there is provided a semiconductor device according to the first aspect, wherein silicon grains are formed in the outer wall of the cylindrical portion to provide projections and recesses in the outer wall surface, and the inner wall is composed of amorphous silicon.

In a third aspect of the present invention, there is

provided a semiconductor device according to the first aspect, wherein the dielectric film is formed on the outer wall, the inner wall and the bottom portion of the cylindrical storage node.

5 In a fourth aspect of the present invention, there is provided a semiconductor device according to the first aspect, wherein an insulating film is formed so as to be in contact with the inner wall and an upper surface of the bottom portion of the cylindrical portion of the  
10 cylindrical storage node, the insulating film constituting the core of the cylindrical portion, and the dielectric film is formed on the outer wall of the cylindrical portion.

15 In accordance with a fifth aspect of the present invention, there is provided a method for producing a semiconductor device having a cylindrical storage node comprising a bottom portion and a cylindrical portion which surrounds an outer circumference of the bottom portion and extends upward, which comprises a step of  
20 forming a contact hole which penetrates an interlayer insulating film formed on a semiconductor substrate; a step of forming an electric conductive film on the interlayer insulating film whereby the contact hole is filled to obtain a contact to the substrate; a step of  
25 forming an insulating film on the electric conductive film; a step of patterning by an anisotropic etching the insulating film and the electric conductive film to form

1 a configuration corresponding to the cylindrical portion  
so that the core and the bottom portion of the  
cylindrical portion are formed; a step of forming the  
cylindrical portion on the side of the core and the  
5 bottom portion wherein an outer wall of the cylindrical  
portion is roughened; a step of removing the core; a step  
of forming a dielectric film to cover the cylindrical  
storage node comprising the cylindrical portion and the  
bottom portion; and a step of forming a cell plate on the  
10 dielectric film, whereby a capacitor constituted by the  
cylindrical storage node, the dielectric film and the  
cell plate is formed.

In accordance with a sixth aspect of the present  
invention, there is provided a method for producing a  
15 semiconductor device having a cylindrical storage node  
comprising a bottom portion and a cylindrical portion  
which surrounds an outer circumference of the bottom  
portion and extends upward, which comprises a step of  
forming a contact hole which penetrates an interlayer  
20 insulating film formed on a semiconductor substrate a  
step of forming an electric conductive film on the  
interlayer insulating film whereby the contact hole is  
filled to obtain a contact to the substrate; a step of  
forming an insulating film on the electric conductive  
25 film; a step of patterning by an anisotropic etching the  
insulating film and the electric conductive film to form  
a configuration corresponding to the cylindrical portion

so that the core and the bottom portion of the cylindrical portion are formed; a step of forming the cylindrical portion on the side of the core and the bottom portion wherein an outer wall of the cylindrical portion is roughened; a step of forming a dielectric film on the cylindrical storage node comprising the cylindrical portion and the bottom portion; and a step of forming a cell plate on the dielectric film, whereby a capacitor constituted by the cylindrical storage node, the dielectric film and the cell plate is formed.

In a seventh aspect of the present invention, there is provided a method for producing a semiconductor device according to the fifth or the sixth aspect, wherein the step of forming the cylindrical portion on the side of the core and the bottom portion wherein an outer wall of the cylindrical portion is roughened, comprises forming amorphous silicon on the core and the bottom portion; roughening an outer surface of the amorphous silicon by forming silicon grains in the outer surface of it; and conducting an anisotropic etching for patterning to form a side-wall like cylindrical portion at the side of the core and the bottom portion.

In an eighth aspect of the present invention, there is provided a method for producing a semiconductor device according to the fifth or the sixth aspect, wherein the step of forming the cylindrical portion on the core and the bottom portion wherein an outer wall of the



1 cylindrical portion is roughened, comprises forming  
2 amorphous silicon on the core and the bottom portion;  
3 conducting an anisotropic etching to form a side-wall  
4 like cylindrical portion at the side of the core and the  
5 bottom portion; and roughening an outer surface of the  
6 amorphous silicon by forming silicon grains in the outer  
7 surface of it to thereby form the cylindrical portion.

8 In a ninth aspect of the present invention, there is  
9 provided a method for producing a semiconductor device  
10 according to the seventh aspect or the eighth aspect,  
11 wherein the roughening of the outer surface of the  
12 amorphous silicon is selected from the group consisting  
13 of a heat treatment with use of silane and a heat  
14 treatment in vacuum after a treatment to the outer  
15 surface of the amorphous silicon with use of hydrofluoric  
16 acid, whereby projections and recesses are formed in the  
17 outer wall of the amorphous silicon by forming silicon  
18 grains in the outer wall.

19 In a tenth aspect of the present invention, there is  
20 provided a method for producing a semiconductor device  
21 according to the ninth aspect, wherein the inner wall of  
22 the cylindrical portion having a roughened outer wall is  
23 constituted by amorphous silicon.

#### BRIEF DESCRIPTION OF THE DRAWINGS

24 A more complete appreciation of the invention and many  
25 of the attendant advantages thereof will be readily  
obtained as the same becomes better understood by

reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

Figure 1 is diagram showing a semiconductor device according to a first embodiment of the present invention;

Figures 2a to 2e are diagrams showing manufacturing steps for the semiconductor device according to the first embodiment of the present invention;

Figure 3 is a diagram necessary for explaining the first embodiment of the present invention;

Figures 4a and 4b are diagrams showing a semiconductor device according to a second embodiment of the present invention;

Figure 5 is a diagram showing a semiconductor device according to a third embodiment and a fourth embodiment of the present invention;

Figure 6 is a diagram showing a conventional semiconductor device; and

Figure 7 is a diagram showing another conventional semiconductor device.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Detailed description of preferred embodiments of the present invention will be described with reference to the drawings wherein the same reference numerals designate the same or corresponding parts.

#### EMBODIMENT 1

Figure 1 is a diagram showing in cross section the

structure of a semiconductor device formed according to the first embodiment of the present invention wherein cylindrical storage nodes for DRAM cells are mainly shown.

In Figure 1, reference numeral 1 designates a semiconductor substrate, numerals 2 designate device isolation oxide layers formed in active regions in the semiconductor substrate, numerals 3 designate word lines as gate electrodes of transistor elements, which are formed by patterning through a gate insulating film, regions interposed by two source/drain regions formed in active regions in the semiconductor substrate 1; and numerals 4a, 4b and 4c designate interlayer insulating films which are subsequently laminated on the transistor elements. The interlayer insulating films 4a, 4b, 4c constitute an interlayer insulating film 4 as a whole. Further, a bit line 5 is formed penetrating the interlayer insulating films 4a and 4b so that the bit line 5 is in contact with one source/drain region 1a between adjacent source/drain regions 1a.

Further, a storage node contact 6a is formed penetrating the interlayer insulating film 4 so that it is in contact with the other source/drain region 1a, and the storage node contact 6a is formed integrally with a cylindrical storage node 6b which comprises a bottom portion 6c and a cylindrical portion 6d which surrounds the bottom portion 6c and extends upward. A dielectric film 7 is formed to cover the cylindrical storage node 6b

and an outer surface of the interlayer insulating film 4. Further, a cell plate 8 is laminated on an outer surface of the dielectric film 7. A cylindrical capacitor 9 is constituted by the cylindrical storage node 6b, the dielectric film 7 and the cell plate 8. Further, an interlayer insulating film 10 is laminated on an outer surface of the capacitor 9.

In the semiconductor device shown in Figure 1, an outer wall of the cylindrical portion 6d of the cylindrical storage node 6b is roughened so that the surface area of the outer wall is increased in comparison with a case without conducting a roughening operation.

A method for producing the semiconductor device shown in Figure 1 will be described with reference to Figure 2.

First, the source/drain regions 1a and the other active elements are formed in the semiconductor substrate 1, and then, the interlayer insulating film 4 of about  $0.15\ \mu\text{m}$  thick is formed on the semiconductor substrate 1, as shown in Figure 2a. A storage node contact hole is formed so as to penetrate the interlayer insulating film 4, and then, an amorphous silicon film 6 is laminated by a chemical vapor deposition method in a film thickness of about  $0.15\ \mu\text{m}$ . The formation of the amorphous silicon film 6 fills simultaneously the storage node contact hole, whereby the storage node contact 6a is obtainable.

Further, a silicon oxide film 11 is formed on the

amorphous silicon film 6 to have a film thickness of about 0.50  $\mu\text{m}$ . The silicon oxide film 11 becomes the core of the cylindrical portion 6d of the cylindrical storage node 6b by a process subsequently conducted.

- 5 Accordingly, it is possible to adjust the film thickness depending on a dimension in a vertical direction of the cylindrical portion 6d.

In the next, a mask pattern having a shape corresponding to the bottom portion 6c of the cylindrical storage node 6b is formed on an outer surface of the silicon oxide film 11, and an anisotropic etching is conducted to the silicon oxide film 11 and the amorphous silicon film 6 by using the mask pattern as an etching mask, whereby the core 11a composed of the silicon oxide film is formed. At the same time, the bottom portion 6c of the cylindrical storage node 6b can be formed. Then, the mask pattern is removed.

Then, an amorphous silicon film 12 having a film thickness of about 0.05  $\mu\text{m}$  is formed by a CVD method on the core 11a and the bottom portion 6c as shown in Figure 2c.

Then, as shown in Figure 2d, a heat treatment as a roughening treatment is conducted to an outer surface of the amorphous silicon film 12 so that the amorphous silicon film 12 becomes to a roughened film 13.

The roughening treatment is described in detail in "a mechanism for forming hemispherical grained

polysilicon" by Tatsumi et al. in Applied Physics  
Academy Magazine in 1992.

As one of the surface roughening techniques, there  
is proposed the formation of hemispherical grained  
5 polysilicon by annealing in vacuum. Namely, the surface  
of an amorphous silicon film is treated with hydrofluoric  
acid, and a heat treatment is conducted at 630°C for a  
predetermined time under a ultra-vacuum condition whereby  
minute projections and recesses of a grain size of 10 nm  
10 to 50 nm are formed. A grain size of 50 nm generally  
corresponds to the film thickness of the formed amorphous  
silicon film 12. However, each silicon grains is in a  
hemispherical shape, and accordingly, silicon grains do  
not reach the inner wall of the cylindrical portion, in  
15 the inner wall and the amorphous silicon film is remained.

As another surface roughening technique, there is  
proposed such technique that the temperature of the  
substrate is kept about 590°C and a  $\text{Si}_2\text{H}_6$  gas is  
introduced so as to conduct nucleation on the outer  
20 surface of the amorphous silicon film 12. In this  
technique, it is possible to adjust conditions for  
treatment such as a substrate temperature, a gas  
introducing time and so on depending on a diameter of  
silicon grains to be formed.

25 Then, as shown in Figure 2e, an anisotropic etching  
is conducted to the roughened film 13 so that only a  
portion of the roughened film 13 attached to a side

surface of the core 11a and the bottom portion 6c is left, which is called, the cylindrical portion 6d. Thus, the bottom portion 6c and the cylindrical portion 6d constitute a cylindrical storage node 6b.

5       After the formation of the cylindrical storage node 6b, the core 11a is removed, followed by forming successively the dielectric film 7 and the cell plate 8 whereby the capacitor 9 as shown in Figure 1 can be obtained.

10       In the cylindrical storage node 6b of the thus formed semiconductor device, a surface roughening treatment can be conducted only from an outer wall side of the cylindrical portion 6d to form the silicon grains. Accordingly, relatively large silicon grains can be  
15       formed even in a case that the film thickness of the amorphous silicon film 12 is small. Accordingly, it is possible to increase the outer surface area of the cylindrical storage node 6b.

Figure 3 is an enlarged view showing in cross  
20       section of the structure of the cylindrical portion 6d. The cylindrical portion 6d comprises the amorphous silicon film 13a and silicon grains 13b.

As shown in Figure 3, the amorphous silicon film 13b remains without discontinuation in the inner wall of the  
25       cylindrical portion 6d, and the surface of the amorphous silicon film 13b is smooth. The remaining amorphous silicon film 13b is sufficient to keep the physical

strength of the cylindrical portion 6b even after the formation of the silicon grains 13b.

Assuming that the cylindrical storage node 6b is in a cylindrical form having a radius (x) of  $0.40\ \mu\text{m}$  and the film thickness from the outer wall to the inner wall of the cylindrical portion 6d is  $0.05\ \mu\text{m}$ , and further assuming that the surface area of the outer wall of the cylindrical portion which has been subject to the surface roughening treatment is 2.5 times as large as the surface area before the surface roughening treatment, the surface area of the storage node can be increased 1.67 times as a whole.

Further, in the semiconductor device according to the first embodiment of the present invention, it is possible to conduct the surface roughening treatment subsequently after the formation of the amorphous silicon film 12 constituting the cylindrical portion 6d. Accordingly, there is no danger of contamination of the amorphous silicon film surface after the treatment, and the formation of projections and recesses can effectively be formed by the surface roughening treatment.

#### EMBODIMENT 2

Description will be made as to the second embodiment of the present invention.

In the above-mentioned first embodiment, the surface roughening treatment is conducted after the formation of the amorphous silicon film which forms the cylindrical



portion of the storage node, and then, an etching-back treatment is conducted so as to obtain the cylindrical portion. In the second embodiment, however, the surface roughening treatment is conducted after the etching-back treatment is conducted to the amorphous silicon film to obtain the cylindrical portion. The finally obtainable structure of the semiconductor device is the same as shown in Figure 1.

In the second embodiment, operations are conducted in the same manner as illustrated in Figures 2a to 2c in the first embodiment. Then, as shown in Figure 4a, an anisotropic etching is conducted to the amorphous silicon film 12 so that the amorphous silicon film 12 is left as a side-wall like cylindrical portion 12a which is attached to a side portion of the core 11a and the bottom portion 6c.

Then, a heat treatment as the surface roughening treatment is conducted in the same manner as described in the first embodiment whereby an outer surface area of the cylindrical portion 6d is increased. In this case, the outer surface at a lower position of the cylindrical portion 6d and near an upper surface of the interlayer insulating film 4, which has not been roughened in the first embodiment, can be roughened.

Assuming that the cylindrical storage node 6b is in a cylindrical form having a radius (x) of  $0.40 \mu\text{m}$  and the film thickness from the outer wall to the inner wall

of the cylindrical portion 6d is  $0.05 \mu\text{m}$ , and further  
the assuming that the surface area of a roughened outer  
wall of the cylindrical portion is 2.5 times as large as  
that without having a roughed outer wall, the surface  
5 area of the storage node can be increased 1.74 times as a  
whole.

Thus, it is possible to conduct the surface  
roughening treatment after the formation of the  
cylindrical portion 6d. In this case, the surface area  
10 of the storage node can be increased while the physical  
strength of the cylindrical storage node 6b can be  
provided and a capacitor 9 of larger capacity can be  
obtained, in the same manner as in the first embodiment.

### EMBODIMENT 3

15 The third embodiment of the present invention will  
be described.

In the first and second embodiments, the silicon  
oxide film which is used as the core 11a is removed in  
forming the cylindrical portion 6d which constitutes the  
20 cylindrical storage node 6b. In the third embodiment,  
however, the core 11a is used without removing.

Figure 5 is a diagram showing in cross section of  
the semiconductor device according to the third  
embodiment wherein numeral 9a designates a capacitor in  
25 which the inner wall and an inner surface of the bottom  
portion of the cylindrical portion 6d of the cylindrical  
storage node 6b are not used as an opposing electrode,

, and only the outer wall is used as an opposing electrode and wherein the core 11a is left inside the cylindrical storage node 6b.

In a method for producing the semiconductor device  
5 shown in Figure 5, the cylindrical storage node 6b and the core 11 are formed in accordance with the processes as shown in Figure 2a to 2e in the same manner as the first embodiment. In the third embodiment, however, the core 11a is not removed and the dielectric film 7 is  
10 formed to cover the capacitor 9a and the core 11a. Then, the cell plate 8 is formed to cover the dielectric film 7.

In the semiconductor device shown in Figure 5, the outer wall of the cylindrical portion 6d constituting the cylindrical storage node 6b is selectively roughened  
15 whereby the outer surface area of the storage node can be increased in comparison with a case that the surface roughening treatment is not conducted to the outer wall.

In the semiconductor device shown in Figure 5, it is impossible for the capacitor 9a to use as an opposing  
20 electrode the inner wall and the bottom portion of the cylindrical portion 6d of the cylindrical storage node 6b. However, assuming that the cylindrical storage node 6b is a cylindrical form having a radius (x) of  $0.40\ \mu\text{m}$  and the surface area of the outer wall is increased 2.5 times  
25 by the surface roughening treatment, the surface area which can be used for the storage node can be increased 1.2 times as large as a case without conducting the

surface roughening treatment to the outer wall.

Further, in this embodiment, since a heat treatment for surface roughening is conducted subsequent to the formation of the amorphous silicon film, the contamination to the treated surface can be prevented and fine projections and recesses can effectively be formed in the outer surface of the cylindrical portion.

Further, since the roughed surface is formed by growing silicon grains only in the outer surface of the cylindrical portion, and the growing of the silicon grains does not reach the inner wall, the formation of air gaps between silicon grains can be eliminated. Further, the physical strength of the cylindrical portion can be assured by leaving the core 11a in the cylindrical storage node 6b.

#### EMBODIMENT 4

In the next, the fourth embodiment of the present invention will be described.

The semiconductor device obtained by the fourth embodiment has substantially the same construction as that shown in Figure 5 concerning the third embodiment, however, there is a difference in the method for producing the same.

Although the cylindrical storage node 6b of the semiconductor device according to the third embodiment is produced in the same manner as that according to the first embodiment, the cylindrical storage node 6b of the

semiconductor device according to the fourth embodiment is prepared according to the processes shown in Figures 4a and 4b in the same manner as the method producing the semiconductor device described in the second embodiment wherein the cylindrical portion 12a of amorphous silicon is formed in a side-wall like form in a side portion of the core 11a, followed by conducting a heat treatment for surface roughening. In the fourth embodiment, the core 11a is not removed.

10 Since the core 11a is left in this embodiment, the inner wall and the bottom portion of the cylindrical portion 6d can not be used as an opposing electrode. However, the outer wall of the cylindrical portion 6d is roughened, and accordingly, the surface area of the outer surface as an electrode can be increased as the whole in the cylindrical storage node 6b.

15 In this embodiment, the surface roughening treatment to the outer wall of the cylindrical portion 6d is conducted after the formation of the cylindrical portion 6d. Therefore, it is possible to form a roughened surface in a lower portion of the cylindrical portion 6d which is near an upper surface of the interlayer insulating film 4, which has not been roughened in the third embodiment. Accordingly, the surface area of the cylindrical storage node 6b can further be increased.

25 For example, when the cylindrical portion 6d is a cylindrical form having a radius (x) of  $0.40 \mu\text{m}$  and the

surface area of the outer wall is increased 2.5 times by the roughening treatment, the surface area of the outer wall can be increased 1.26 times in comparison with a case without conducting the roughening treatment.

5        In the fourth embodiment of the present invention, the roughened surface is formed by growing silicon grains only in the outer wall of the cylindrical portion 6b to an extent that the growth of the silicon grains does not reach the inner wall. Accordingly, the formation of air  
10       gaps between the silicon grains can be suppressed.

Further, since the core 11a is left in the cylindrical storage node 6b, the physical strength of the cylindrical portion 6b can be assured.

15       In accordance with the semiconductor device in the first aspect of the present invention, the outer wall of the cylindrical storage node is roughened and inner wall is not roughened. Accordingly, it is possible to increase the surface area of the storage node while a sufficient physical strength of the cylindrical portion  
20       can be assured.

Further, in the semiconductor device according to the second aspect, the surface roughening treatment is conducted by forming silicon grains only in the outer wall wherein the size of the silicon grains is increased  
25       to thereby increase the surface area of the outer wall. Further, silicon grains are not formed in the inner wall where an amorphous silicon layer is remained.

Accordingly, the formation of air gaps between silicon grains can be suppressed and the physical strength of the cylindrical portion can be maintained.

In the semiconductor device of the third aspect, in addition to the advantage described in the first aspect, the capacity of the capacitor can further be increased since the inner wall and the bottom portion of the cylindrical storage node is used as an electrode of the capacitor.

In the semiconductor device of the fourth aspect, in addition to the advantage described in the second aspect, the physical strength of the cylindrical portion can certainly be maintained and the destruction and the breakage of the cylindrical portion can be avoided since the insulating layer which is used as the core of the cylindrical portion is left without removing from the cylindrical storage node.

In the method for producing a semiconductor device according to the fifth aspect of the present invention, since the cylindrical portion in which only the outer wall is roughened is formed as a structural element of the cylindrical storage node, the surface area of the capacitor can be increased, and the physical strength of the cylindrical portion can be assured because the inner wall of the cylindrical portion is not roughened. Further, the insulating layer used as the core of the cylindrical portion when the cylindrical portion is

formed, is removed, the inner wall and the bottom portion of the cylindrical storage node are used as an opposing electrode.

In the method for producing a semiconductor device according to the sixth aspect, since the cylindrical portion in which only the outer wall is roughened is formed as a structural element of the cylindrical storage node, the surface area of the capacitor can be increased, and the physical strength of the cylindrical portion can be assured because the inner wall of the cylindrical portion is not roughened.

In the seventh aspect of the present invention, the cylindrical portion having its roughened side wall is formed by forming an amorphous silicon film on the entire surface of the core; roughening the outer surface of the amorphous silicon film, and conducting an anisotropic etching for patterning to obtain the cylindrical portion in a side-wall form attached to the core.

According to the eighth aspect of the present invention, the cylindrical portion having the roughened outer wall is formed by forming an amorphous silicon film on the side surface of the core in a side-wall form and roughening the outer surface of the amorphous silicon film.

According to the ninth aspect of the present invention, the amorphous silicon film is roughened by a heat treatment with use of silane or  $\text{Si}_2\text{H}_6$ , or by a



treatment with a hydrofluoric acid followed by heat treatment in vacuum. In either method, silicon grains can be formed to increase the surface area with good controllability. Further, in either method for surface roughening, an excellent roughened surface is obtainable without contamination of the surface to be treated for surface roughening.

In the tenth aspect of the present invention, the amorphous silicon film remains in the inner wall of the cylindrical portion and any air gaps are not formed in the inner wall. Accordingly, it is possible to maintain the physical strength of the cylindrical portion.

Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.